INTERNATIONAL FOOD
POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty

Supported by the CGIAR

IFPRI Discussion Paper 00984

May 2010

Improving Resource Allocation and Incomes in Vietnamese Agriculture

A Case Study of Farming in the Dong Nai River Basin

Joshua Dewbre

Environment and Production Technology Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI) was established in 1975. IFPRI is one of 15 agricultural research centers that receive principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR).

PARTNERS AND CONTRIBUTORS

IFPRI gratefully acknowledges the generous unrestricted funding from Australia, Canada, China, Denmark, Finland, France, Germany, India, Ireland, Italy, Japan, the Netherlands, Norway, the Philippines, South Africa, Sweden, Switzerland, the United Kingdom, the United States, and the World Bank.

AUTHOR

Joshua Dewbre, American University
Gradudate Student (2009), M.A. Development Economics
jdewbre@gmail.com

Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at http://www.ifpri.org/publications/results/taxonomy%3A468.

[2] IFPRI Discussion Papers contain preliminary material and research results. They have been peer reviewed, but have not been subject to a formal external review via IFPRI's Publications Review Committee. They are circulated in order to stimulate discussion and critical comment; any opinions expressed are those of the author(s) and do not necessarily reflect the policies or opinions of IFPRI.

Contents

List of Tables

List of Figures

ABSTRACT

This paper uses data collected in an extensive survey of farm costs in the Dong Nai River Basin of Vietnam to estimate the parameters of production functions for rice, vegetables, and coffee. These estimates are then combined with price information to estimate marginal value products for irrigation, fertilizer, labor, and other farm inputs. Comparing marginal value products of the various inputs across crops and with factor prices suggests there may be potential for improving resource allocation and farm incomes. One novel contribution is the consideration of water and irrigation—a concern of considerable interest amidst rising water scarcity in the region.

Most notably, the results indicate that fertilizer is the primary constraint to increased yields and farm income. Across all crops the marginal return to phosphorous, for example, ranges from 6,000–20,000 Vietnamese dong (VND) (US$1 = VND1, 800).Making similar comparisons with irrigation water suggests there is potential for improving resource allocation by diverting water from vegetables and coffee toward rice production. The marginal return to irrigation water for rice production is VND 2,500. For coffee and vegetables, marginal returns are negative.

For vegetables, preliminary evidence suggests that all irrigation water is not created equal—groundwater and sprinkler irrigation systems have marginal physical products more than double that of traditional sources.

Keywords: farm input allocation, irrigation efficiency, water allocation policy, Vietnam, Dong Nai basin, translog production function

ACKNOWLEDGMENTS[1]

This paper builds directly on the progress achieved by Sarah Cline in processing the survey data and conducting a preliminary analysis of it for an unpublished term paper at Colorado State University. The survey was administered in the Dong Nai River basin under the auspices of the Vietnamese Sub-National Institute for Agricultural Planning and Projections (Sub-NIAPP) and the International Food Policy Research Institute (IFPRI) under the leadership of Claudia Ringler. Special thanks to Claudia Ringler, Elizabeth Bryan, Walter Park, and an editor for valuable comments on an earlier draft. All mistakes are my own.

[1] During the writing of this paper, Joshua Dewbre was a Summer Intern (2009) for IFPRI's Environment, Production and Technology Division.

ABBREVIATIONS AND ACRONYMS

DEA	data envelopment analysis
Sub-NIAPP	Sub-National Institute for Agricultural Planning and Projections
MPP	marginal physical products
MVP	marginal value products

1. INTRODUCTION

The Dong Nai River Basin in southern Vietnam covers an area of 48,471 square kilometers (km^2) and is an important region for agricultural and industrial production. The basin includes the nation's capital, Ho Chi Minh City, which is the country's largest city, a major port, and the commercial and industrial center of the country.

The basin's population is relatively affluent, although there are some low-income areas in Ninh Thuan and Binh Phouc provinces as well as in rural parts of Binh Thuan, Dak Lak, and Lam Dong provinces.

Agriculture's contribution to Vietnam's national GDP has consistently decreased in recent decades, but the sector remains vibrant and importantly linked to food security and development goals. In 2008 agriculture accounted for approximately 20percent of GDP, down from 40percent in the early 1990s. The sector has become increasingly diversified, and today produces agricultural staples (notably rice), raw materials (such as rubber), and cash crops (such as coffee and vegetables).

The importance of agriculture to regional economies varies greatly from province to province, with agriculture still making up the majority of GDP in some provinces such as Dak Lak (71 percent), Binh Phuoc (65 percent), Lam Dong (60 percent), Long An, and Ninh Thuan (53 percent each) (Ringler, Huy, and Msangi, 2006).

Water allocation has recently become an important issue in government planning due to increased water scarcity, the vulnerability of water resources and reforms in the water sector. With this increased emphasis on water resources, allocation of water between agriculture and other uses has been the focus of many previous research efforts in the basin. Increasing competition between agricultural and other types of water use has made estimates of the importance and efficiency of water use for different agricultural crops useful for agricultural sector planning.

The three crops chosen for study here provide a good sampling of agricultural production in Vietnam today. Rice is a natural choice for analysis given present objectives both because it is historically the most important staple crop produced in the basin and because of its very high water requirements. Vegetable production is also widespread, and of particular interest due to its comparatively low water intensity and high value. Coffee, on the other hand, is the crop with the highest value and has featured prominently as part of the country's export-oriented growth strategy.

The remainder of this paper is structured as follows. The next section provides a brief overview of the literature related to the estimation of production functions and previous research on the agricultural sector in Vietnam. Section 3 discusses data and the methods used for the estimation of the production functions. The final two sections present the results and provide conclusions and policy implications.

2. LITERATURE REVIEW

Several studies in recent years pursued objectives similar to those motivating the present analysis and used survey data to estimate the parameters of production or cost functions. Linde-Rahr (2003) analyzes whether rice and sugarcane farmers in North Vietnam are profit-maximizing with respect to their input usage. She uses survey data collected in 1998 from rural households in the Hoa Binh Province to estimate a translog production function to derive marginal products of labor, capital, fertilizer, pesticide, and land. By testing the equality of returns to factor inputs and the technical rate of substitution, the author concludes that farmers were using inputs efficiently.

In contrast, Lichtenburg and Nguyen (2001) asked the same general question using data from South Vietnam and found that farmers are inefficient in their input usage. The authors use data envelopment analysis (DEA) to consider the simultaneous production of three outputs: traditional and modern varieties of rice and aquatic animals. Nonparametric methods like DEA are sometimes used to consider multiproduct production frontiers that allow for input substitution. Conducting statistical tests to determine whether the inputs exhibit weak disposability—an indication of negative marginal productivity—the authors conclude that pesticides, labor, and fertilizer are being used at rates that impair crop productivity.

In examining reasons for low rates of application of fertilizer in Zambia, Xu et al. (2009) uses longitudinal household survey data to calculate marginal products from maize yield response functions. They specify a quadratic and exponential model using human capital variables and apply an “asymmetric” approach that dichotomizes agronomic inputs (water and nutrients, for example) and “facilitating” inputs (education, machinery). Although their findings vary by region and time period, the general story emerging from their analysis is that, indeed, farmers apply suboptimal amounts of fertilizer to the extent that profits could be increased given observed prices. The authors note that the low uptake was generally due to uncertainty on behalf of the farmers. They attribute this to the significant variation of fertilizer’s (nitrogen’s) marginal product across time periods and market inefficiencies (such as the unpredictable distribution of fertilizer by vendors) that further reduced incentives for farmers to invest in fertilizer.

The suboptimal application of fertilizer has emerged as a flagship example in discussions of poor farmer rationality in technology adoption. Conducting field experiments on maize farmers in Kenya, Duflo, Kremer, and Robinson (2008) find that optimal applications of fertilizer can significantly increase farm incomes, but the rates of application commonly chosen by some farmers, including those recommended by experts from the Kenyan Ministry of Agriculture, lead to profits that are sometimes lower than if the farmer had applied no fertilizer at all.

Again, looking at fertilizers, Ekbom and Sterner (2008) adopt a model similar to that of Xu et al., incorporating soil nutrients and human capital but using a modified translog specification to estimate total value of agricultural production. From this, they derive elasticities of various production inputs, finding positive elasticities for nitrogen and potassium and negative elasticities for phosphorus application in Kenya.

While some of these studies include water as an input in the estimation of the production function, none explicitly consider water’s role. One exception is Ringler, Huy, and Msangi (2006) who develop a model combining economic and hydrologic components to evaluate the efficiency and profitability of irrigation in the Dong Nai River basin. The study finds that irrigation water applied to coffee and vegetables is more profitable and productive than irrigation water applied to rice and other paddy crops. Moreover, the analysis reveals the potential for large water savings in the agricultural sector by increasing irrigation efficiency.

3. DATA

The data come from a household survey administered to 700 farm households in 11 provinces in the Dong Nai River basin under the auspices of the Vietnamese Sub-National Institute for Agricultural Planning and Projections (Sub-NIAPP) and the International Food Policy Research Institute (IFPRI). The survey was implemented between summer and autumn of 1999 and the winter and spring of 2000. One of the main purposes was to obtain primary data needed to analyze the efficiency of irrigation water use, including its optimal allocation among competing uses. Specifically, the information collected and used in this paper includes crop-specific quantities produced and prices received as well as quantities of inputs used and their costs. Table 1 provides descriptive statistics for the data.

Table 1. Sample means and standard deviations

	Rice	Standard deviation	Vegetables	Standard deviation	Coffee	Standard deviation
Variable	(n=732)		(n=318)		(n=76)	
Yield(ton/ha)	4.18	0.79	18.39	10.03	2.54	0.69
Nitrogen(kg/ha)	100.41	32.03	234.05	103.96	274.38	107.29
Phosphorous(kg/ha)	65.97	33.47	198.99	123.35	186.16	74.81
Potassium(kg/ha)	23.04	15.8	38.57	33.03	82.73	39.27
Irrigation (mm/ha)	305.71	248.91	205.25	164.93	343.14	122.08
Rain(mm/ha)	359.82	155.00	165.42	89.13	856.20	140.50
Labor(person days/ha)	74.83	25.09	254.41	200.06	340.35	79.17
Machinery(VND1,000/ha)[a]	512.18	177.71	498.71	347.12	114.24	103.17
Pesticide(VND1,000/ha)	410.02	244.20	1,412.03	1,541.52	1,095.05	817.50

Source: Sub-NIAPP and IFPRI.
Notes: [a]VND=Vietnamese dong; 1USD= 1,800VND

Most of the variables are self-explanatory but some deserve additional attention. Information on area harvested and quantity of production was taken for each household. Yield was then calculated by dividing production by area harvested. Detailed crop-specific information on both expenditures and quantities used of the following inputs were collected: fertilizers (including urea, ammonium sulfate, diammonium phosphate, superphosphate, lime, manure, and so forth) irrigation water, and labor (including both hired and family labor). In the case of fertilizers, survey respondents reported the quantities and costs for the types of fertilizers (mixes) they actually purchased. Using formulas representing the chemical composition of each of these types of fertilizer, total aggregates for nitrogen (N), phosphorous (P), and potassium (K) applied to each crop were calculated for use in estimating the production relationships of most interest to the present study. The only information available for machinery is an estimate of total expenditures given that most farmers rent machinery services due to small farm size. Likewise, given the large variety and mixes for pesticides, only cost of use was incorporated into the estimation. Notice that data measuring water use is distinguished between that supplied by irrigation and that from rainfall. This distinction was maintained when estimating the production function to allow for the possibility of there being some differences in the associated yield impacts on the various crops.

Output prices used subsequently to calculate marginal value products come directly from national sources for the Dong Nai River Basin in 2000, the survey year of the data. Independent input prices were not available for the regions covered in the survey, so unit value prices are constructed by dividing observations of reported input expenditure by reported quantity used in the survey data. Also, because the prices paid by farmers vary based on crop as well as transport and handling costs, the averages for each crop are taken for simplicity.

A comparison of means and standard deviations in Table 1 reveals that, generally speaking, the variation of yields and input quantities is much less for rice and coffee than for vegetables, possibly reflecting the diversity of products incorporated in the vegetable aggregate.[1] Even more striking is the relatively higher variability of input use than of yields across all three output categories. Especially notable in this connection is the relatively high variability in water use. This could of course reflect the underlying diversity of growing conditions but suggests as well the possibility of significant deviations of input use around the economically optimal quantities – an issue explored further below.

[1] Vegetables included: Aubergine, bitter melon, cabbage, carrot, cauliflower, chili, Chinese pea, cucumber, French bean, gourd, green beans, green peas, herbs, lettuce, onion, red bean, spinach, squash, tomato, and waky pumpkin.

4. CHOICE OF MODEL

There is little consensus as to the "correct" functional form to represent production relationships. Finger and Hediger 2008 emphasize the trade-offs between simplicity and flexibility that analysts must make in choosing the functional form best suited to their objectives. In light of such considerations, a Cobb-Douglas (C-D) and a so-called flexible form, the transcendental logarithmic (translog) function, were chosen to explore practical insights into the optimality and profitability of various inputs to crop production.

The enduringly popular C-D form offers ease of computation and interpretation and is widely applied in the literature. The simplicity of this model derives from assumptions of homogeneous technology, where the marginal rates of substitution of all input pairs are independent of the quantities of other inputs used, and all equal unity. When all variables are in logarithms, the C-D function permits linear estimation where the input coefficients are interpreted to be the elasticities of production.

Equation (1) presents a generalized form of the C-D equation used in the analysis.

$$\ln(Y) = \alpha_0 + \sum_i \beta_i \ln(Z_i) + \sum_k \gamma_k D_k + u \quad , \qquad \textbf{(1)}$$

where

Y= yield per hectare,
Zi= inputs to production per hectare,
Dk= season and province dummies, and
u= error term.

However, the restrictions the C-D implicitly imposes on input interactions may significantly reduce the reliability and usefulness of empirical estimates (Heady and Dillon 1961). Because of the strong restrictions imposed on technology, more flexible forms—which imply that nothing is known about the production process—are used for comparison.

Results obtained in estimating the C-D form of the yield equations are shown below in Table 2. A majority of the estimated coefficients in the rice and vegetable equations are statistically significant with expected positive coefficients on the input variables. Only irrigation and labor in the coffee equation are statistically significant, perhaps owing to the relatively smaller sample size (76 observations) for coffee. Nevertheless, all of them except the one for irrigation are positive.

As measured by the R^2, the equations for all three explain a surprisingly high proportion of the variation in the yield data.

Table 2. Results from Cobb-Douglas

	Rice		Vegetables		Coffee	
Parameter	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
<u>Input</u>						
Nitrogen [N]	0.10	5.28	0.40	8.90	0.10	0.76
Phosphorous [P]	0.02	2.24	0.01	0.21	0.11	0.96
Potassium [K]	0.00	0.12	0.04	2.48	0.11	1.31
Irrigation [I]	0.02	6.11	0.03	2.11	-0.23	-2.01
Rain [R]	-0.03	-2.66	-0.02	-1.19	0.40	0.86
Labor [LAB]	0.04	1.59	0.15	3.01	0.22	1.25
Machinery [M]	0.01	0.90	0.05	5.54	0.05	2.59
Pesticides [Pe]	0.04	4.16	0.01	0.49	0.06	1.55

Table 2. Continued

	Rice		Vegetables		Coffee	
Parameter	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Province						
Baria	0.01	0.33	0.39	2.23	0.31	1.42
Binhduong	0.03	0.83	-0.29	-3.51		
Binhphuoc	-0.01	-0.25	-0.09	-0.57	0.25	1.50
Binhthuan	0.10	3.44	-0.26	-3.35	0.09	0.46
Dongnai	0.03	0.87	-0.81	-7.06	0.28	1.74
Daklak	…	…	…	…	0.41	2.36
Longan	0.00	-0.14	-0.39	-5.30		
Ninthuan	0.21	6.53	-0.40	-5.71		
Ho Chi Minh City	0.01	0.17	-0.70	-8.09		
Tayninh	-0.10	-3.74	-0.53	-7.62		
Season						
Summer	0.02	1.36	0.03	0.63		
Winter	0.05	2.44	-0.03	-0.61		
Constant	0.53	3.75	-0.31	-0.99	-4.27	-1.43
Adj R^2	0.48		0.71		0.44	

Source: Author's calculations.

The translog form consists of both linear and quadratic terms that can generalize across specific models and production technologies (Christensen, Jorgensen, and Lau 1973). This particular form is attractive in that it allows a full range of interaction effects among the inputs—an especially appealing feature in the present application because, in contrast to the C-D, there are no prior restrictions dictating the elasticities of substitution. The translog is additionally attractive because of the ease with which the usual theoretical restrictions: non-decreasing, linear homogeneity, and constant returns to scale may be imposed on the estimation. Finally, the translog is chosen because of its wide application in the literature and because, among all flexible forms, it is generally regarded as being superior (Tzouvelekas 2000). The main feature of the translog is to make the marginal productivities, or the production elasticities, depend on the input combination for which these coefficients are calculated (Mundlak 2001).

A generalized form of the translog regression equation used in this analysis is represented in equation (2).

$$\ln(Y) = \alpha_0 + \sum_i \beta_i \ln(Z_i) + \frac{1}{2}\sum_i \sum_i \beta_{ij} \ln(Z_i)\ln(Z_j) + \sum_k \gamma_k D_k + u \qquad \textbf{(2)}$$

where again,

Y= yield per hectare,
Zi= inputs to production per hectare,
Dk= season and province dummies, and
u= error term.

In order for the production function to be homothetic and to impose constant returns to scale the following constraints were imposed:

$$\sum_i \beta_i = 1, \sum_i \beta_{ij} = 0$$

The restrictions imposed in estimating the translog equation ensure that coefficient estimates are consistent with several of the desirable mathematical properties of production functions.

Coefficient estimates obtained in estimating the three crop yield functions from the translog are presented in Table 3. Considering the high degree of variability in the data, the statistical significance of the coefficients of the estimated equations is highly satisfactory in the case of rice and vegetables. For rice, 31 out of 57 (55 percent) of the coefficients were statistically significant, and 25 out of 57 (45 percent) were significant for vegetables.

The R^2 is not defined in the case of the translog model. However, an indication of how well the estimated yield equations fit the data is possible by comparing predicted and observed yield values. Appendix A contains such comparisons (see Appendix Figures A.1, A.2). These R2's reveal a goodness of the fit of the estimated equation that is relatively high for cross-section analyses. As compared to the C-D, the theoretical and statistical properties of the translog were judged superior in the case of rice and vegetables. Moreover, as will be seen below the estimates of the marginal physical products of the various input derived from the estimated translog coefficients are, in general, economically meaningful, that is, they can be used to make judgments about optimal resource allocations.

In the case of coffee, none of the input coefficients are statistically significant in the translog specification. This is surprising in view of the explanatory power of the model suggested by the correlation between predicted and observed values (see Appendix Figure A.3.). Of course, this again may be due to low sample size (76) relative to the number of estimated coefficients inherent of the translog. However, it proved impossible to derive economically meaningful interpretations from the coffee input coefficients obtained using the translog specification. Accordingly, and despite the higher explanatory power of the translog version, the C-D was chosen for subsequent analysis of resource allocation in coffee production.

Table 3. Results from the translog function

	Rice		Vegetables		Coffee	
Parameter	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Input						
Nitrogen [N]	0.15	1.62	0.57	4.99	0.54	0.38
Phosphorous [P]	-0.04	-0.69	0.17	1.82	-1.07	-0.75
Potassium [K]	0.24	4.8	0.06	0.69	1.85	1.27
Irrigation [I]	0.15	8.12	0.18	4.23	0.78	0.64
Rain [R]	0.07	1.38	0.16	2.98	-2.04	-0.95
Labor [LAB]	0.39	4.12	-0.26	-2.47	0.68	0.41
Machinery [M]	0.12	3.32	0.13	3.14	0.51	1.6
Pesticides [Pe]	-0.07	-1.65	0	-0.13	-0.25	-0.49
N x N	0.21	3.32	-0.2	-1.45	0.7	0.46
P x P	-0.01	-0.56	0.22	3.32	-0.7	-0.46
K x K	0.04	3.57	0.01	0.36	0.27	0.43
I x I	0.05	8.17	0.04	2.97	0.64	0.9
L x L	0.27	3.53	-0.05	-0.57	-1.76	-0.85
M x M	0.04	4.22	0.05	3.21	0.03	0.6
Pe x Pe	0.03	3.96	0.01	0.5	0.04	0.44
R x R	0.05	5.2	0.05	2.14	0.34	0.18
N x P	-0.06	-2.29	0	0.07	-0.29	-0.3
N x K	-0.03	-1.11	0.09	2.42	0.05	0.07
N x I	-0.01	-0.77	-0.09	-3.06	-0.51	-0.74

Table 3. Continued

	Rice		Vegetables		Coffee	
Parameter	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
N x L	-0.1	-1.81	0.27	2.77	1.02	1.03
N x M	-0.06	-2.09	0.01	0.18	-0.03	-0.19
N x Pe	0.05	1.62	-0.05	-1.74	-0.13	-0.35
N x R	0.01	0.2	-0.03	-0.77	-0.81	-0.59
P x K	0.05	4.06	-0.04	-0.98	0.16	0.25
P x I	0	-0.11	-0.02	-1.14	-0.26	-0.34
P x L	-0.05	-1.5	-0.07	-1.07	0.02	0.03
P x M	0.08	3.1	-0.04	-2.15	0.05	0.36
P x Pe	0	0.06	-0.01	-0.51	0.13	0.37
P x R	0	0.03	-0.05	-2.47	0.89	1.03
K x I	0.01	1.81	0.03	2.17	0.36	0.75
K x L	-0.01	-0.43	-0.13	-4.78	0.09	0.13
K x M	0	-0.04	0	-0.27	0.06	0.3
K x Pe	-0.05	-4.49	0.01	1.08	0.12	0.64
K x R	-0.01	-0.85	0.03	1.67	-1.11	-1.51
I x l	-0.01	-1.86	-0.01	-0.37	-0.01	-0.01
I x M	0.01	1.92	0	0.07	0.07	0.31
I x Pe	-0.02	-5.43	-0.01	-0.84	-0.32	-1.29
I x R	-0.02	-2.36	0.05	2.29	0.03	0.03
L x M	-0.06	-2.15	-0.03	-1.31	0.14	0.77
L x Pe	0	0.17	0.06	1.97	-0.05	-0.19
L x R	-0.04	-1.58	-0.04	-1.3	0.56	0.37
M x Pe	-0.01	-1.33	0.01	0.75	-0.1	-1.77
M x R	0.01	0.6	0.01	0.71	-0.21	-0.61
Pe x R	0	-0.07	-0.01	-1.95	0.31	0.76
Province						
Baria	0.13	3.37	0.26	0.48	-0.07	-0.18
Binhduong	0.12	3.06	0.12	1.13		
Binhphuoc	-0.11	-1.78	0.32	1.94	0.52	1.38
Binhthuan	0.14	4.85	0.29	3.03	0.01	0.05
Daklak					0.55	1.39
Dongnai	0.12	3.46	-0.02	-0.17	0.01	0.02
Lamdong	0.03	0.96	0.47	6.73		
Longan	0.04	1.37	0.17	1.75		
Ninthuan	0.17	3.88	0.17	1.64		
Ho Chi Minh City	0.16	4.64	-0.31	-2.7		
Season						
Summer	-0.08	-3.94	0.04	0.93		
Winter	0.01	0.36	-0.01	-0.15		
Constant	-3.43	-32.27	-2.72	-18.22	-2.45	-1.59

Source: Author’s calculations.

5. RESULTS

Because of the large number of interaction terms in the translog equation, the model parameter estimates cannot provide any immediate economic interpretation of the effects of the specific inputs, making it difficult to discern the theoretical consistency of results by looking just at the numerical estimates of the various coefficients.[1] To achieve those insights, the coefficients can be used to estimate marginal physical products (MPP)—the change in yield from a one unit increase in a given input, all else equal—for each one of the eight inputs. Results achieved in doing so are discussed in the following section.

Marginal Physical Products (MPP)

Taking the partial derivatives of equations (1) and (2) with respect to the various inputs yields the following formulas for the marginal products in the C-D and translog models:

$$\frac{\partial Yield}{\partial Z_i} = \beta_i \frac{\widetilde{Y}}{Z_i}, \text{ and} \qquad \textbf{(1a)}$$

$$\frac{\partial Yield}{\partial Z_i} = [\beta_i + 2\sum_j \beta_{ij} \ln(Z_j)] \frac{\widetilde{Y}}{Z_i} P, \qquad \textbf{(2a)}$$

where the tilde indicates predicted values. In order to generate statistical properties of these estimates, all calculations were computed using the delta method evaluated at sample means. The delta method calculates the variance using a one-step Taylor series approximation to expand a function of a random variable about its mean (Greene 2003). The results from doing so are presented in Table 4.

Theory dictates that all MPPs should be positive, as it would be irrational for farmers to use inputs that reduce production. Notice that almost all marginal products displayed in Table 4 are indeed positive. Two notable exceptions with statistically significant negative signs are potassium in rice production and irrigation in coffee production.[2] While errors in data collection may be causing this result, it is also possible that farmers are indeed over applying potassium and irrigation water. This could happen if farmers do not possess the necessary technical information enabling them to choose appropriate application rates. Alternatively, even with that knowledge, they may lack sufficient control over the delivery mechanisms due, for example, to inadequate or outdated technology.

[1] It is possible, however, to directly interpret the estimated parameters relating output and inputs in the C-D function for coffee.

[2] A comparison of results in Tables 2 and 3 show the importance of focusing on partial effects of the respective inputs and not on the regression coefficients, per se. Notice in the case of rice, for example, that despite negative own coefficients on pesticide and phosphorous (in the translog model), these inputs maintain positive partial effects.

Table 4. Estimated marginal physical products for selected crops

	Rice	Vegetables	Coffee
	(n=732)	(n=318)	(n=76)
Input			
Nitrogen	0.0112**	0.0101	0.0009
	(2.88)	(1.07)	(0.76)
Phosphorous	0.0069*	0.0141	0.0014
	(2.01)	(1.41)	(0.96)
Potassium	-0.0157*	0.0121	0.0033
	(-2.28)	(0.54)	(1.31)
Irrigation	0.0022***	0.0014	-0.001**
	(6.61)	(0.35)	(-2.01)
Rain	0.0030***	-0.0029	0.0011
	(4.53)	(-0.57)	(0.86)
Labor	-0.0023	0.0310***	0.0016
	(-0.39)	(3.96)	(1.25)
Machinery	0.0019***	0.0089***	0.0011**
	(4.53)	(3.89)	(2.59)
Pesticide	0.0009	0.0001	0.0001
	(1.82)	(0.23)	(1.55)

Source: Author's calculations.
Notes: Results for coffee are derived from Cobb-Douglas specification.
T-statistics are in parentheses:* p<0.05, ** p<0.01, *** p<0.001.

In addition to being positive, optimal resource allocation requires that the MPPs be decreasing in inputs. That is, the rate at which additional inputs increase yields should be decreasing. This implies that the following expressions hold for the C-D and translog specifications respectively:

$$[-\beta_i \frac{\widetilde{Y}}{Z_i^{\ 2}}] < 0 \qquad \textbf{(1b)}$$

$$[(\beta_i + \sum_j \beta_{ij} \ln(Z_j)] * [(\beta_i - 1 + \sum_j \beta_{ij} \ln(Z_j)] < 0 \quad . \qquad \textbf{(2b)}$$

For coffee (C-D), 1b holds for all inputs except irrigation. For vegetables (translog) 2b holds for all inputs, and for rice all except potassium and labor. In all those cases where conditions 1b and 2b do not hold, that is, where the second derivative of the MPP is positive, the corresponding estimates of the MPPs are negative.

Marginal Value Products (MVP) and Factor Prices

Apart from the fact that the numerical values of the marginal products are mostly positive and exhibit diminishing marginal returns, little more can be learned from looking at them in isolation. Further progress necessitates calculating marginal value products (MVPs) and examining relative price relationships.

The MVP of an input is the extra value of the increase in output caused by a unit increase in the use of that input (such as the MPP). For allocative efficiency, an input's MVP should equal its marginal cost.

Whereas theory alone is insufficient to allow meaningful comparisons of MVPs across factors for a given crop (because this requires knowledge of input prices), it is meaningful to compare MVPs for the same factor across crops. Indeed, in theory, these should be equal. But, as an empirical matter, this requires some strong assumptions about, in particular, the objectives and knowledge of farmers. They are supposed to be operating to maximize profits under conditions of perfect markets and full information. While there are few reasons to doubt that farmers in poor countries seek to maximize profits, doubt that they do so in light of perfect information in perfect markets is plentiful.

Table 5. Estimated marginal value products for selected crops

	Rice		Vegetable		Coffee	
Input		Prices		Prices		Prices
Nitrogen	17.01**	6	19.06	12	8.327	10
Phosphorous	10.46*	6	26.69	6	13.18	7
Potassium	-23.87*	8	22.79	8	30.59	8
Irrigation	3.358***	1	2.731	4	-15.41*	4
Rain	4.67***		-5.59		10.68	
Labor	-3.51	20	58.53***	20	14.92	20
Machinery	2.883***		16.89***		10.14*	

Source: Author's calculations.
Notes: Results for coffee derived from Cobb-Douglas specification. Prices have been rounded to the nearest VND 1000. Prices for machinery and pesticides could not be calculated from the data due to missing data and aggregation issues, respectively.
* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 5 presents the MVPs for the various crops. Recall that these numbers were obtained by valuing the estimated MPPs of each of the various inputs at average prices of the three outputs. Ideally then the next step in evaluating whether farmers are, on average, choosing the profit maximizing levels of input use would be to compare these MVPs with the associated factor prices. However, in some cases there is no meaningful factor price information available. An important case is where the associated factor is, from the farmer's perspective, fixed in production with, in effect, zero opportunity costs. The usual examples are farm family labor and owned land. Another possibility, of particular relevance to this analysis, would be a fixed limit on the quantity of irrigation available to an individual farmer.

All is not lost, however, since, even for fixed inputs, it is still meaningful and interesting to compare differences among MVPs across output categories. Consider first the differences in the MVPs for irrigation among the various crops. The results for irrigation imply that farm income could be increased by VND 3,400 in rice and by VND 2,700 in vegetable production by increasing irrigation water. This implies that profitable investments in additional irrigation could be made if the unit costs of water provided were less than VND 2,700.

Additionally, in seeking the optimum allocation of fixed resources, the farmer would want to shift irrigation away from the output offering the lower MVP toward the ones offering the higher MVPs. Of course in practice, such reallocations may not be feasible because of features of reality not captured in simple yield equations. Nonetheless, results in Table 5 imply that the total value added by irrigation could be increased by shifting some water currently devoted to vegetables toward rice production.

As noted earlier, in the case of coffee, the results suggest that irrigation water is being over- or incorrectly applied to such a degree that additional irrigation water reduces income and yields. One tenuous explanation for this may be that producers are still in the learning stage—coffee being a relatively new crop in Vietnam. Another potential explanation is that coffee farmers are using inappropriate irrigation technology. In this case farmers may be unable to appropriately adjust the delivery of water in response to changing climactic conditions. While it is not possible to differentiate between irrigation technologies for coffee, the data do indicate that almost 60 percent of coffee producers used surface water—as opposed to groundwater—for their irrigation.

A related finding from Table 5 is that rainwater is more productive than irrigation water for rice and coffee. In the case of coffee, an additional unit of rainwater increases the value of production by about VND 11,000. There may be qualitative differences between the two water sources (such as contamination) or, more likely, this finding might simply reflect the fact that some 20 percent of farmers in the sample had no access to irrigation.

The over application of potassium in rice production and irrigation in coffee production are important issues meriting further investigation in future research.

Factor Prices

Additional progress in evaluating whether factor use by rice, vegetable, and coffee farmers is optimal, that is, whether there are ways that farm incomes could be increased by altering input combinations, requires comparison of MVPs and input prices. Specifically under the same strong assumptions of perfect information, perfect markets, and profit-maximizing behavior, one would expect to observe farmers utilizing inputs up to the point where the MVP equals the marginal cost. Differences between observed MVPs and corresponding factor prices indicate how much value added might be increased by using more or less of that factor.

A first observation in making the comparisons in Table 5 is that farmers are, in general, underutilizing fertilizers. Note that with the exception of potassium in rice production, profits could be raised by increasing application rates of all fertilizers for all crops.

For example, rice farmers could increase their marginal returns, (the incremental improvement in total returns less the cost of additional input use) by VND 11,000 by applying an extra unit of nitrogen and about VND 4,000 for additional phosphorus. The same calculation gives a similar increment to vegetable producer returns. In the case of coffee, the marginal return for potassium is approximately VND 18,000.

Note that if measurement error is not to blame for the negative sign on potassium, marginal returns could be improved by reducing application rates. Viewed from an environmental perspective such findings constitute evidence of a possible “win-win” opportunity, in that both farm profits could be increased and the burden of fertilizer use on the environment reduced at the same time.

The single biggest opportunity to increase farm income, seen in Table 6, comes from increasing labor in vegetable production. Valuing family and hired labor at a reported daily wage of VND 20,000, additional labor would increase income by approximately VND 40,000. By contrast, for rice and coffee production, farm profits might be increased by allocating labor either to other crops on the farm or to off-farm work. Of course, valuing farm family labor at the prevailing wage rate is problematic. It assumes that farm families can flexibly alter the allocation of their work and leisure time between working on their own farm and working for wages elsewhere. If instead such labor were assumed to be a fixed resource, as it often is, the MVP results in Table 6 would suggest some labor time could be profitably reallocated away from rice and coffee toward vegetable production.

Irrigation would similarly be considered a fixed resource if the water is allocated by a government authority. In this case, the results emerging from Table 6 suggest that a diversion of current irrigation water from vegetables and coffee toward rice production would generate the highest gross value added. However, if the farmer is able to purchase additional units of irrigation water at the same prices, an additional unit of water would generate net income gains of approximately VND 3,000 for rice. For both coffee and vegetables, profits could be increased by decreasing the amount of irrigation water applied.

While finding a good explanation for this is beyond the scope of this paper, the data do permit investigation into the relative productivities of irrigation technology and water sources. In the sample, farmers derived irrigation water through either surface (lakes, streams) or ground (wells) sources and used either sprinkler or furrow irrigation systems.[3] Groundwater and sprinkler irrigation systems are generally considered to be more efficient and productive than irrigation using surface water and furrow methods (Schoengold and Zilberman 2007). Because no rice farmers used ground water and very few coffee farmers (14) used sprinkler irrigation, the analysis has been confined to vegetable producers. Of these, half derived their irrigation water from ground surfaces and 40 percent relied upon sprinkler technologies.

To test whether there are indeed differences between these alternatives, equation (2) was augmented by two interaction variables and re-estimated. Both variables included irrigation and were interacted with a water source dummy (equal to one for groundwater and zero for surface) and a technology dummy (equal to one for sprinkler irrigation and zero for furrow), respectively. In a regression context, the estimated coefficients are interpreted to be the additional effect of irrigation from using groundwater or sprinkler irrigation. The results from doing this (not presented) were positive and statistically significant. Using these coefficients, marginal physical products were calculated by applying formula (2a) and are displayed in Table 6.

Table 6. Relative productivities of irrigation water source and technology

	Vegetables
Source	
Surface	0.0010
	(0.24)
Ground	0.0021
	(0.50)
Technology	
Furrow	0.0010
	(0.24)
Sprinkler	0.0033
	(0.77)

Source: Author's calculations.
Note: t-statistics are in parentheses.

While the results for vegetables are not statistically significant, it is nevertheless interesting to note that groundwater and sprinkler irrigation have substantially higher estimated MPPs. According to Table 6, the MPP of groundwater is double that of surface water. Similarly, the MPP of sprinkler irrigation is triple that of furrow. While this evidence is preliminary and tenuous, it does highlight the importance of considering the role of irrigation technology in future research.

[3] Furrow irrigation includes border and flooding.

6. CONCLUSION

Using a household survey from the Dong Nai River Basin in Vietnam, this paper estimates crop production functions for rice, vegetables, and coffee using Cobb-Douglas and translog functional forms.

Across all crops, the results indicate that fertilizer is the primary constraint to increased yields and farm income. Marginal returns to phosphorous, for example, range from VND 20,000 in the case of coffee to roughly VND 5,000 for rice and vegetables. Similarly, for rice and vegetables, there are high returns to additional applications of nitrogen and potassium in coffee production. Strategies that would encourage the use of profitable fertilizers and discourage the use of nonprofitable fertilizers should be pursued.

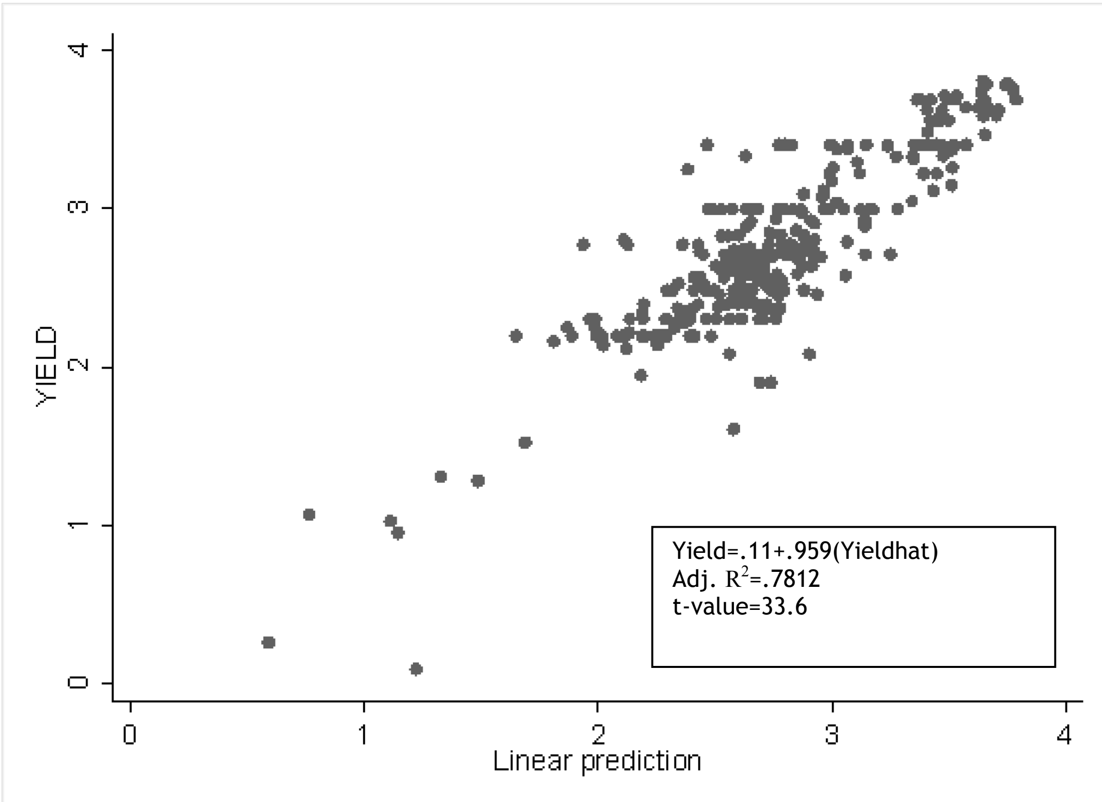
Some fertilizers are being over applied, however, and there is potential for both environmental and efficiency gains to be achieved from reducing their use. This emphasizes the importance of ensuring that fertilizers are adapted to local biophysical conditions—a possible recommendation for farm-level extension services.

With respect to water the results depend on whether additional irrigation is available to the individual farmer. If additional irrigation water is purchasable, there would be relatively small but positive marginal returns to additional use for rice and vegetable producers. If, however, irrigation is fixed, the reallocation of existing sources toward vegetable production would result in higher value added to farmers. Additionally these findings suggest that additional investments in irrigation for rice and vegetable production might be warranted if unit costs could be kept below the corresponding marginal value products. One key consideration meriting further research and data collection is the role that technology and water source play in the production process. Preliminary evidence presented here suggests that groundwater and sprinkler irrigation technology may offer greater productivity and efficiency than traditional methods in vegetable production.

Future extensions of research using the same data set might incorporate regional prices for machinery and pesticides and investigate the institutions and markets governing irrigation water allocation in the Dong Nai Basin.

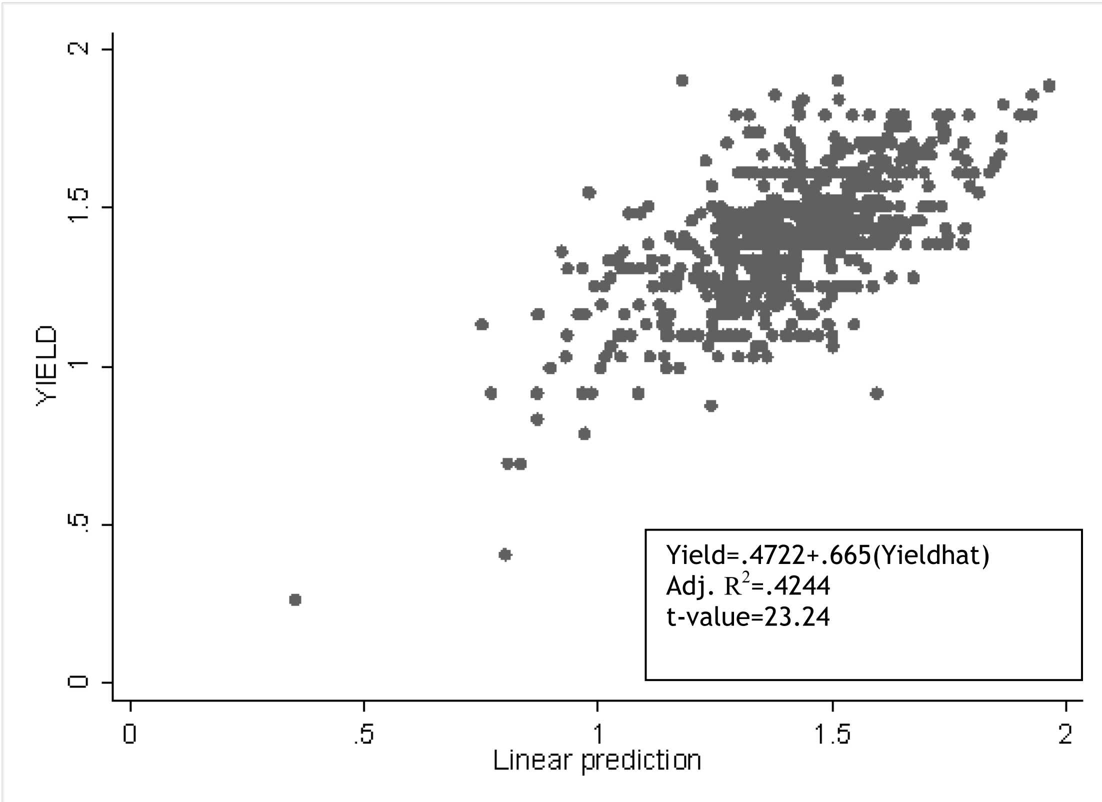
APPENDIX: SUPPLEMENTARY FIGURES

Figure A.1. Predicted yield and observed yield for vegetables



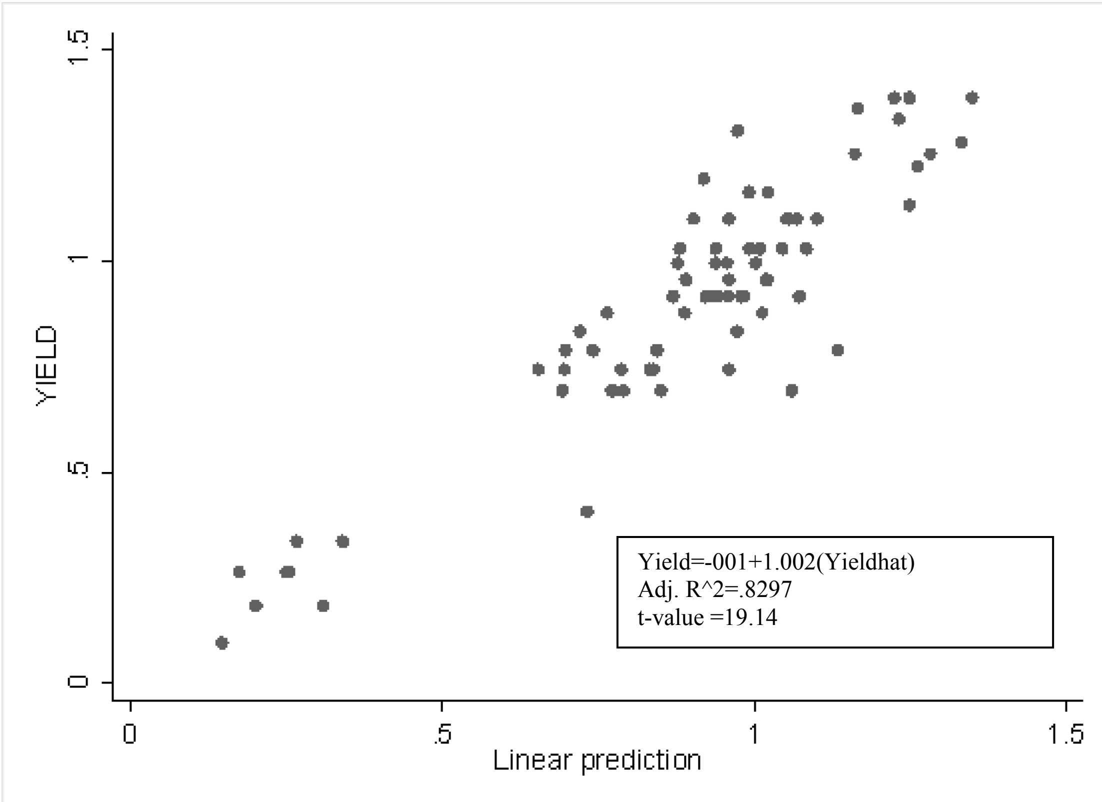
Source: Author’s calculations.

Figure A.2. Predicted yield and observed yield for rice



Source: Author's calculations.

Figure A.3. Predicted yield and observed yield for coffee



Source: Author's calculations.

REFERENCES

Christensen, L. R., D. W. Jorgenson, and J. J. Lau. 1973. Transcendental logarithmic production frontiers. *The Review of Economics and Statistics* 55 (February): 28–45.

Cline, S. 2005 The Role of Water Use in Crop Production in the Dong Nai Basin, Vietnam. Colorado Springs, Colo., U.S.A: unpublished term paper.

Dina, A., and J. Letey. 1996. *Modeling economic management and policy issues of water in irrigated agriculture*. Westport, Conn., U.S.A.: Praeger.

Duflo, E., M. Kremer, and J. Robinson. 2008. How high are rates of return to fertilizer? Evidence from field experiments in Kenya. *American Economic Review* 98 (February): 482–188.

Ekbom, A., and T. Sterner. 2008. *Production function analysis of soil properties and soil conservation investments in tropical agriculture*. Environment for Development Discussion Paper Series. Gottenberg, Sweden: Environment for Development.

Finger, R., and W. Hediger. 2008. *The application of robust regression to production function comparison—The example of Swiss corn.* Zurich, Switzerland: Institute for Environmental Decisions.

Greene, W. H. 2003. *Econometric analysis*. Upper Saddle River, N.J., U.S.A.: Prentice-Hall.

Heady, E. O., and J. L. Dillon. 1961. *Agricultural productivity function*. Ames, Iowa, U.S.A.: Iowa State University Press.

Lichtenberg, E., and K. L. T. Nguyen. 2001. *Pesticide productivity in green revolution rice production: A case study of Vietnam*. Chicago, Ill.: American Agricultural Economics Association.

Linde-Rahr, M. 2003. Differences in agricultural returns: An empirical test of efficiency in factor input allocations using Vietnamese data. *Agricultural Economics* 32: 35–45.

Mundlak, Y. 2001. Production and supply. In *Handbook of Agricultural Economics*, ed. B. L. Gardner, and G. C. Rausser. Amsterdam: Elsevier.

Ringler, C., N. V. Huy, and S. Msangi. 2006. Water allocation policy modeling for the Dong Nai River Basin: An integrated perspective. *Journal of the American Water Resources Allocation* 42 (December): 1465–1482.

Schoengold, K., and D. Zilberman. 2007. The economics of water, irrigation, and development. In *Handbook of Agricultural Economics*, ed. R. Evenson, and P. Pingali. Amsterdam: Elsevier.

Tzouvelekas, E. 2000. Approximation properties and estimation of the translog production function with panel data. *Agricultural Economics Review* 1 (January): 33–47.

Xu, Z., Z. Guan, T. S. Jayne, and R. Black. 2009. Factors influencing the profitability of fertilizer use on maize in Zambia. *Agricultural Economics* 40: 437–446.

RECENT IFPRI DISCUSSION PAPERS

For earlier discussion papers, please go to http://www.ifpri.org/publications/results/taxonomy%3A468.
All discussion papers can be downloaded free of charge.

983. *Positional spending and status seeking in rural China*. Philip H. Brown, Erwin Bulte, and Xiaobo Zhang, 2010.

982. *Assessing food security in Yemen: An innovative integrated, cross-sector, and multilevel approach*. Olivier Ecker, Clemens Breisinger, Christen McCool, Xinshen Diao, Jose Funes, Liangzhi You, and Bingxin Yu, 2010.

981. *Long-term impact of investments in early schooling: Empirical evidence from rural Ethiopia.* Subha Mani, John Hoddinott, and John Strauss, 2010.

980. *Infrastructure and cluster development: A case study of handloom weavers in Ethiopia*. Gezahegn Ayele, Lisa Moorman, Kassu Wamisho, and Xiaobo Zhang, 2010.

979. *Country-level impact of global recession and China's stimulus package: A general equilibrium assessment*. Xinshen Diao, Yumei Zhang, and Kevin Z. Chen, 2010.

978. *Emergence of Sri Lanka in European fish trade: Is there cause for concern in the Lake Victoria Region (East Africa)?* Andrew Muhammad and Guyslain Ngeleza, 2010.

977. *China has reached the Lewis Turning Point*. Xiaobo Zhang, Jin Yang, and Shenglin Wang, 2010.

976. *The medium-term impact of the primary education stipend in rural Bangladesh*. Bob Baulch, 2010.

975. *A review of empirical evidence on gender differences in nonland agricultural inputs, technology, and services in developing countries.* Amber Peterman, Julia Behrman, and Agnes Quisumbing, 2010.

974. *An experiment on the impact of weather shocks and insurance on risky investment.* Ruth Vargas Hill and Angelino Viceisza, 2010.

973. *Engendering agricultural research.* Ruth Meinzen-Dick, Agnes Quisumbing, Julia Behrman, Patricia Biermayr-Jenzano, Vicki Wilde, Marco Noordeloos, Catherine Ragasa, Nienke Beintema, 2010.

972. *Sarpanch Raj: Is the president all powerful? The case of village councils in India.* Nethra Palaniswamy, 2010.

971. Asset *versus consumption poverty and poverty dynamics in the presence of multiple equilibria in rural Ethiopia*. Lenis Saweda O. Liverpool and Alex Winter-Nelson, 2010.

970. *Poverty status and the impact of social networks on smallholder technology adoption in rural Ethiopia.* Lenis Saweda O. Liverpool and Alex Winter-Nelson, 2010.

969. *Wage subsidies to combat unemployment and poverty: Assessing South Africa's options*. Justine Burns, Lawrence Edwards, and Karl Pauw, 2010.

968. *Patterns and trends of child and maternal nutrition inequalities in Nigeria.* Babatunde Omilola, 2010.

967. *Foreign inflows and growth challenges for African countries: An intertemporal general equilibrium assessment.* Xinshen Diao and Clemens Breisinger, 2010.

966. *Biofuels and economic development in Tanzania.* Channing Arndt, Karl Pauw, and James Thurlow, 2010.

965. *Weathering the storm: Agricultural development, investment, and poverty in Africa following the recent food price crisis.* Babatunde Omilola and Melissa Lambert, 2010.

964. *Who has influence in multistakeholder governance systems? Using the net-map method to analyze social networking in watershed management in Northern Ghana.* Eva Schiffer, Frank Hartwich, and Mario Monge, 2010.

963. *How to overcome the governance challenges of implementing NREGA: Insights from Bihar using process-influence mapping.* Katharina Raabe, Regina Birner, Madhushree Sekher, K.G. Gayathridevi, Amrita Shilpi, and Eva Schiffer, 2010.

962. *Droughts and floods in Malawi: Assessing the economywide effects*. Karl Pauw, James Thurlow, and Dirk van Seventer, 2010.

961. *Climate change implications for water resources in the Limpopo River Basin*. Tingju Zhu and Claudia Ringler , 2010.

960. *Hydro-economic modeling of climate change impacts in Ethiopia*. Gene Jiing-Yun You and Claudia Ringler, 2010.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

www.ifpri.org

IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org